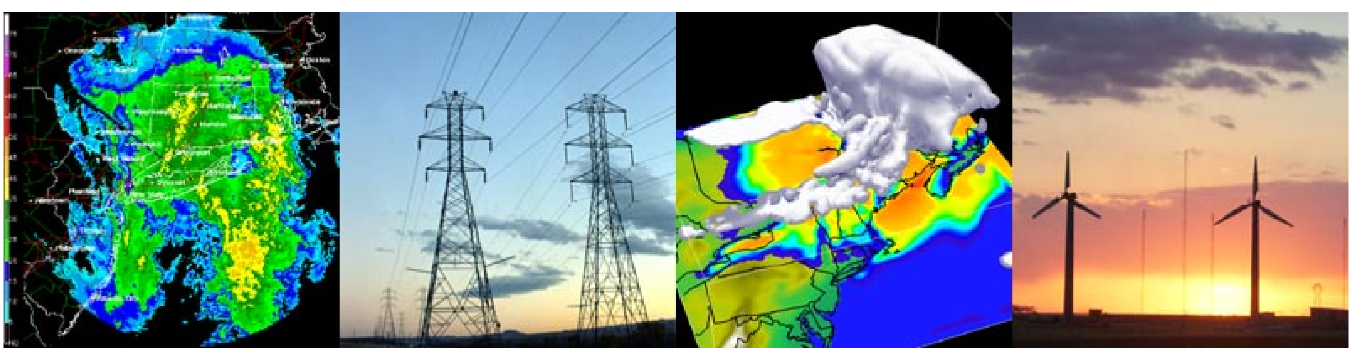
Minnesota Department of Commerce

Regional Wind Analysis

State Wind Speed Map



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Minnesota Department of Commerce
State Wind Resource Mapping

Project Overview

In mid-2005 the Minnesota Department of Commerce (MN DOC) contracted WindLogics, a St. Paul company, to develop a new state-of-the-art wind resource map. Using the best available weather data sources and the latest physics-based weather modeling technology and statistical techniques, WindLogics created a statewide map with a horizontal grid resolution of 500 meters. The new map is based on data and modeling methodologies which accurately represent the full three-dimensional nature of the atmosphere rather than relying solely on simple point-based measurements. In addition, the resulting data have been statistically adjusted to accurately represent long-term (40 year) wind speeds over the state, thereby incorporating important decadal weather trends and cycles.

Methodology Description

The WindLogics Weather Data Archive and modeling system were used to model the wind activity for the entire state of Minnesota. The WindLogics data archives were used as input to the modeling system. Hourly time series were run for a full year period and statistics were accumulated on a monthly and annual basis. The results were then normalized to long-term climatic means using forty years of data from the WindLogics NCEP/NCAR Reanalysis data archive (see description below).

Though the initial methodology plan was to use tower data collected by the MN DOC field program as part of the analysis, this data was not directly used in the study. The number of useful sites was limited, as only sites generating data over the particular year covered by the modeling study were candidates for comparison. Based upon analysis of the MN DOC tower hardware configuration, measured wind speed and directional distributions, and comparison to several other data sets (WindLogics Data Archives, METAR readings from ASOS automated surface observation system stations, and other available met tower data sets), much of the MN DOC tower data was found to show questionable representation of the free-stream wind speed. For this reason, the WindLogics science team, in consultation with MN DOC staff, decided to exclude this data source in the final analysis.

Data Sources

The wind resource mapping over the state of Minnesota was based on weather data archives collected by the US National Weather Service (NWS) in partnership with worldwide weather services. As a member of the World Meteorological Organization, the NWS has access to vast amounts of weather data from nearly every country, military and private enterprise throughout the world. These data provide a rich source of wind information when combined with physics-based atmospheric modeling techniques developed by WindLogics. Two elements of the WindLogics Weather Data Archives were used in the MN DOC statewide wind resource mapping project:

- ***WindLogics North American Archive***
  - One year of hourly, 20 km three-dimensional (3D) gridded weather data

- ***WindLogics Worldwide Reanalysis Archive (NCEP/NCAR Reanalysis data)***
  - 40 years of 6 hourly, 210 km 3D gridded weather data

In both cases, the data comes from multiple sources, includes wind, temperature, pressure measurements and other weather parameters that are blended in a physically consistent process, and employs the equations of physics to infer relationships between the quantities. In addition to direct wind measurements themselves, the process takes into account the pressure pattern, which forces the wind, and the spatially variable temperature profile, which has a strong influence on the vertical distribution of wind speed.

These “gridded analyses” are valuable for wind energy resource analysis because they capture the upper air information gathered from remote sensing satellites, the radiosonde network, the ACARS aircraft network and numerous other data sources used in the NWS assimilation process. These data sources are accessed through WindLogics’ multiple NOAAport satellite receiver systems and stored online at the WindLogics Data Center. WindLogics has collected well over two terabytes of weather data to date. The NWS data comes from a variety of collection methods such as:

- Aircraft data through the ACARSW system
- Wind Profilers (404 and Boundary Layer 915 Mhz)
- Rawinsondes and dropwindsondes
- Surface stations
- VAD winds from WSR-88D NEXRAD radars
- SSM/I total precipitable water estimates
- GPS total precipitable water estimates
- GOES total precipitable water estimates
- GOES high-density visible and IR cloud drift winds
- GOES cloud drift winds
- GOES cloud-top pressure
- RASS virtual temperatures
- Buoy data
- Ship reports

6-year WindLogics North American Archive
WindLogics has an exclusive six-year weather archive over the contiguous United States, most of Canada and northern Mexico. This data collection represents the National Weather Service’s best available, real-time hourly data analysis of the state of the atmosphere over North America. These data utilize a spatial grid of 40 km (1999-2002) or 20 km (2003-2004) with a time spacing of one hour. The presence of a grid point every 40 (or 20) km in the archive does not imply a physical tower location. Rather, the gridded analysis that the WindLogics archive includes is produced by a process of “data assimilation” which minimizes the effect of errors in individual observations.

56-Year WindLogics Global Reanalysis Archive
The National Centers for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) have cooperated in a project (called "Reanalysis") to produce a retroactive 56-year (1948 - 2004) record of global analyses of atmospheric fields in support of the needs of the research and climate monitoring communities. This effort involved the recovery of land surface, ship, rawinsonde, pibal, aircraft, satellite and other data, quality controlling and assimilating these data with a data assimilation system that is kept unchanged over the reanalysis period. This process is designed to eliminate perceived climate jumps associated with changes in the operational (real-time) data assimilation system. The reanalysis system continues to be used with current data in real time so that its products are available from 1948 to the present.

The NCEP/NCAR 56-year reanalysis uses a frozen modern global data assimilation system, and a database as complete as possible. The data assimilation and the global spectral model are identical to the global system implemented operationally at NCEP, except that the horizontal resolution is about 210 km (depending on latitude). The database has been enhanced with many observations not available in real time for operational use provided by different countries and organizations and gathered mostly at NCAR. Most data fields are saved four times a day (every 6 hours). This 56 year data archive is periodically updated as new processing and modeling techniques become available. The continuous improvement to the entire data set means that every year of data has been treated in a consistent manner.

The NCEP 56-year archive is stored in the WindLogics 3D data format called MeRAF (**Me**ta **R**andom **A**ccess **F**ile). WindLogics has developed special software code to parse this massive data set and extract average wind data from the archive at turbine hub height over the entire planet. Resulting average wind speed information can be used to normalize the data modeled from the hourly data source described above. Normalization implies taking into account differences between the relative windiness of the study period and the longer-term span, so that the normalized result is representative of long-term mean properties.

This WindLogics study utilized 40 years of the long-term data to normalize the wind speed results to a long-term climatological means.

Atmospheric Modeling

The study incorporated surface terrain, land cover and land use information in addition to the weather data described above. WindLogics extracted wind speed information from the atmospheric modeling system at three heights above ground level (AGL) - 30 meters, 80 meters and 100 meters.

Based on the one-hour modeling time series and the normalization process, gridded fields of average annual and monthly wind speeds were developed for Minnesota. High-resolution modeling fields were computed based on the source meteorological data (WindLogics Data Archives) including wind, pressure, temperature, and humidity.

Different types of atmospheric modeling approaches are available and it is customary to distinguish between “prognostic” and “diagnostic” models. Prognostic models predict the meteorological fields based on a mathematical representation of all the relevant physical processes. Prognostic models are widely used to represent complex physical processes that drive atmospheric flow systems, generating dynamically consistent three-dimensional fields with spatial resolution on the order of several kilometers. Diagnostic models consider some simplification of the equation of motion such as linearization or the conservation of mass. Diagnostic windfield modeling has been widely used in evaluations of wind flow patterns over complex terrain. This WindLogics study used a two-part modeling approach incorporating both prognostic and diagnostic atmospheric models in order to generate the most accurate results possible.

Mesoscale Meteorological Modeling (Prognostic Modeling)

WindLogics employed the NCAR / Penn State Mesoscale Model 5th Generation (MM5) to prepare the source data at a resolution appropriate for wind analysis. The “MM5 mesoscale model” is the latest in a series of mesoscale meteorological models that were developed from a model originally created at Penn State in the early 1970’s. MM5 is an advanced numerical weather model used for research and operational forecasting around the world. MM5 was developed as a community mesoscale model and as such, it is continuously being improved by contributions from users at more than 200 universities, commercial sites (such as WindLogics) and government laboratories around the world, including the US National Weather Service and US Air Force.

The MM5 model:

- Incorporates advanced non-hydrostatic physics models to produce accurate representation of small-scale wind flows
- Predicts local thermally forced flows, such as sea-breeze and slope flows

One year of the 20-km resolution data from the WindLogics North American Archive was used as input to the MM5 mesoscale modeling system with a final grid resolution of 3 km. The physics-based, full-atmospheric results from the MM5 modeling process, representing a 12-month time span, were used as input to the diagnostic windfield models during the second phase of the modeling process.

Diagnostic Windfield Modeling (Diagnostic Modeling)

The WindLogics diagnostic windfield modeling process is designed to fit meteorological observations in a complex terrain environment while also satisfying the principle of mass conservation, thereby determining flow patterns over complex terrain. The advantage of this modeling process is that it:

- Computes all hours in long-term datasets, not just a sampling
- Takes into account the atmosphere’s thermal structure and generates resulting terrain steering of the flow
- Can be run from WindLogics gridded analyses, mesoscale model data, and any combination of available surface tower and upper air observations

The model output data created from the mesoscale modeling phase of the project was used as the initial input to the diagnostic windfield models. 500-meter terrain and land-cover data (collected from the United States Geological Survey, USGS) were also used as input into the windfield models. WindLogics ran 197 windfield model grids, with the final resolution of 500 meters, to efficiently cover the entire state of Minnesota. The output of these models consists of full monthly data sets that were then blended together in a GIS-based mosaic process to create a full state, 12-month representation of the wind resource at 30 m, 80 m, and 100 m above ground level.

Data Analysis and Mapping

Following the modeling phases, WindLogics took several steps to validate the results of the modeling output. These steps included analyzing and comparing the model results to METAR and ASOS readings throughout the state, the (September 2004) MN DOC / Xcel Energy Wind Integration Study results, and Rapid Update Cycle (RUC) archived wind data.

METAR and ASOS readings: WindLogics analyzed the data from several METAR and ASOS stations across the state to help validate the results of the models and the DOC met tower data.

MN DOC / Xcel Energy Wind Integration Study: A comparison between the annual 80 m wind speed map with overlapping regions of the 80 m annual wind speed map produced for the 2004 MN DOC / Xcel Energy Wind Integration Study generally reveals only minor differences of a few tenths of one meter per second for gross topographic features. Given that the prior modeling effort had a grid spacing of 5 km, the notable difference between these maps involves the much-improved resolution of smaller-scale topographic features than the 2004 MN DOC study was incapable of resolving.

Rapid Update Cycle (RUC) archived wind data: The 12-month model dataset was directly compared to readings from the WindLogics Rapid Update Cycle (RUC) wind dataset. These comparisons were done at several locations scattered throughout the state.

Following the modeling phases, the resulting gridded data was analyzed and processed for long-term (40 year) normalization, and assembled into statewide file structures. By comparing the Reanalysis wind speed for the model year with the long-term (forty-year) wind speed average for Reanalysis grid points adjacent to and within the study area, a ratio is obtained that is applied to the results from the WindLogics modeling process. For example, if the long term (forty-year) average wind speeds for the nearby Reanalysis point were 5% slower than the wind speeds during the model year for that Reanalysis point, then the WindLogics modeled wind speeds in that part of the grid would be decreased by 5% to adjust to the long-term average.

This normalization process created monthly and annual 40-year normalized wind speed maps for 30 m, 80 m, and 100 m AGL. Also, included are normalized gross energy production and capacity factor maps for the Vestas V82 1.65 MW MKII turbine at the 80 m level. This data can be viewed within the delivered ArcGIS package.

Preparation of WindLogics Geographic Information System (GIS) Data

Once processing and modeling was complete, the data was exported to the IMG (ERDAS Imagine) raster file format using custom software built in to ESRI's ArcGIS geographic information system. The original map projection, datum and grid point spacing was retained so that there is a one-to-one relationship between each grid point in the original WindLogics data file and each raster cell in the final output raster data. No interpolation, generalization, geographic transformation or other change of the original values or their location was necessary to perform this conversion.

The raster datasets were assembled and grouped by height and model variable into layers for cartographic display in ArcGIS. The final cartographic product and data was exported and packaged as a PMF (Published Map File) and its associated data packages. These data packages hold the original wind model data and a large amount of base data such as county boundaries, roads, water features, transmission lines, landmarks, METAR stations, WindLogics Weather Data Archive points, city boundaries, etc. The base data were included for the state of Minnesota as a convenient reference to enhance the cartographic product's usefulness as a geographic analysis tool, however WindLogics cannot vouch for the specific accuracy of these map elements and the state Land Management Information Center may have more up-to-date information that could be easily combined with the WindLogics results. The published map file is viewable with ESRI's freely available ArcReader program. The installer for ArcReader is available from ESRI's website and is also included on the DVDs we delivered. The published map file and its associated data were left "unlocked" and thus are editable, viewable and usable in the same way a MXD (Map Document) file would be used in the full ArcGIS software package available from ESRI.

Intended Use and Limitations of State Wind Resource Map

This new statewide wind resource map offers a much improved and useful tool to view the state's wind resources, though users should be aware that on-site measurements as part of a detailed wind resource assessment at any given site within the state would utilize even more detailed windfield modeling and significantly higher resolution terrain information. Such site-specific analysis would be able to resolve small-scale features that exert significant influences on the local wind speeds. Combining on-site meteorological tower data with modeling and long-term data analyses will further refine the wind resource analysis. Therefore, the Windlogics wind resource map produced for this study is best used for general planning purposes to compare the relative windiness of different areas within Minnesota.

As described in this report, the most comprehensive and reliable meteorological and topographical data sources available were used to create the wind resource map. Nevertheless, unknown inaccuracies or missing components in these base data sets would impact the results.

As noted above, the wind speed, energy production, and capacity factor data included in the ArcGIS package are the result of WindLogics' own analyses, whereas the other overlays and information (transmission lines, landmarks, etc.) are provided to MN DOC as a convenience only, with no assurances given by WindLogics about the complete accuracy of such additional overlays.